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Coralligenous morphotypes on subhorizontal substrate: a new categorization

Valentina A. BRACCHI[1,2]*, Alessandra SAVINI[1,2], Daniela BASSO[1,2], Fabio MARCHESE[1,2], Cesare CORSELLI[1,2]

[1] University of Milano-Bicocca, Department of Earth and Environmental Sciences Piazza della Scienza 4, 20126 Milano, Italy.

[2] CoNISMa, Local Reasearch Unit of Milano-Bicocca, Piazza della Scienza 4, 20126 Milano, Italy.

*Corresponding author: valentina.bracchi@unimib.it

Abstract
Coralligenous has a relevant role in submarine landscape formation and demise through geological times, producing various morphotypes on the seafloor. Several terms are used to define coralligenous morphotypes, but their application through different geological and environmental settings still remains inconsistent. Through a systematic analysis of seafloor acoustic remote data (multibeam, side scan sonar and subbottom profiler) along Apulia continental shelf, ground-truthed by video observations and direct sampling, we detected a number of coralligenous morpho-acoustic facies as 0.2 up to 4 m topographic reliefs with steep flanks and a rigid inhomogeneous biogenic framework, characterized by medium to strong SSS backscatter and a variable plan-view geometry. The observed pattern led to the identification of coralligenous meso- and macrohabitat in which the biogenic frameworks (i.e. coralligenous) prevail as sole biocommunity on the seafloor or are associated with other type of habitats: (i) coralligenous *sensu stricto*, (ii) coralligenous and detritic bottom, (iii) coralligenous and muddy bottom, (iv) coralligenous and *Posidonia* meadow. Finally we improve the geomorphological definition of bank, proposing this new descriptive rigorous categorization for coralligenous morphotypes on sub-horizontal substrate: 1) tabular bank, 2) discrete relief, and 3) hybrid bank.

Keywords
coralligenous; morphotypes; submarine geomorphology; remote sensing; seascape; Mediterranean Sea.

1. Introduction
In the framework of Mediterranean marine benthic zonation, coralligenous (C) is a biocenotic complex generating a new solid substrate, mainly produced by the accumulation of calcareous encrusting algae growing in dim light conditions, and consisting of tridimensional biogenic build-ups (Laborel, 1961; Pérès and Picard, 1964; Bellan-Santini et al., 1994; Bressan et al., 2001; Ballesteros, 2006; Piazzi et al., 2012). As other benthic bio-constructions, it contributes to seascape formation through geological times, causing geomorphological changes of the seafloor. In the Mediterranean Sea, it represents the most monumental bioconstruction along the shelf, where it forms large structures that may be up to 4 m high and greater than 50 m in

lateral continuity (Bosence, 1983, 1985). Architecture and morphology are primarily controlled by biological carbonate productivity that responds to climate, oceanography, physiography, changes in accommodation space and terrigenous supply (Schlager, 1991, 1993; Betzler et al., 1997).

The legal framework for the management of European marine waters recognized marine bioconstructions under the “reefs” category as habitats worth of protection (European Community, 1992). Despite its ecological importance and conservation value, our knowledge of C distribution and natural variability is still inadequate (UNEP-MAP-RAC/SPA, 2008; Agnesi et al., 2009; UNEP, 2011; Martin et al., 2014) and several efforts have been promoted in order to fill this gap. The extent to which C tridimensional structures can change in space and time has never been thoroughly investigated, and a consistent terminology, that could efficiently address the diversity of C morphotypes, is still missing.

Marine bionomists consider the C substrate to be a key factor in distinguishing the C *d’horizon inférieur de la roche littorale*, always on an antecedent hard substrate, from the C *de plateau*. Originally the latter was indicated as a biogenic framework developed from the coalescence of rhodoliths (Pérès and Picard, 1951; Nalin et al., 2006; Basso et al., 2007); then it was generally signaled as forming a solid substrate settled on an originally mobile substrate (Pérès and Picard, 1964). However, some authors suggest that some C *de plateau* frameworks could have grown on submarine rocky outcrops (Got and Laubier, 1968; Laborel, 1987).

C morphotypes have not been exhaustively categorized. Only two general categories are reported (Pérès and Picard, 1964; Laborel, 1987; Ballesteros, 2006): 1) banks – flat frameworks with thickness ranging from 0.5 to 4 m mainly built over more or less horizontal substrata, and 2) rims – structures on submarine vertical cliffs or surrounding the opening of submarine caves, generally located in shallower waters than banks. With this approach, the key factor to distinguish the two morphotypes is basically the geometry of the substrate, sub-horizontal *versus* sub-vertical. Consequently, all the occurrences of C on sub-horizontal substrate, that is to say on most of the continental platform, should be ascribed to the bank category *sensu* Ballesteros (2006). Although the scientific literature contains a variety of terms used to refer to different morphotypes of C build-ups (heads, blocks, patches, or banks, Sarà, 1968; vertical pillar, Di Geronimo et al., 2002; algal reefs, Bosence, 1983; mound-shaped algal banks, Toscano and Sorgente, 2002; minute reef aggregation, Georgiadis et al., 2009; columns and ridges, Bracchi et al., 2015), all of them fall into the bank category. According to Ballesteros (2006), C *de plateau* falls always into the bank category, disregarding its original substrate, and overcoming the genetic implications of its original bionomic definition (Pérès and Picard, 1951). The C *d’horizon inférieur de la roche littorale* type falls into the rim category. On the contrary, banks growing on hard substrate do not correspond to any bionomic definition (Bracchi et al., 2015).

Apulian C is known in literature since decades (Sarà 1966; 1968; Sarà & Pulitzer-Finali, 1970; Parenzan, 1983). Large areas of the Apulian continental shelf have been investigated by acoustic methods from the coastline down to 100 m water depth, in the framework of the BIOMAP project and of a commercial survey.

We identified a combination of distinct C morphological expression, at the scale of meso-habitat sensu Greene et al. (2001), based on distinctive and ground-truthed C morpho-acoustic facies.

Our goal is to describe precisely and quantitatively the morphotypes associated with the coralligenous habitat, which is the basic knowledge on which all the ecological/biological information will be built upon. This approach takes into account the variability of C distribution and 3D development, using a morphometric, non-interpretative approach, in order to propose an objective, consistent, and geomorphological classification, as a powerful tool for habitat mapping.

2. Materials and methods

We analyzed acoustic data obtained from ship-based research surveys, performed between March 2012 and October 2012, under the framework of the BIOMAP project (Fig. 1a, b). Data spanned areas located offshore Puglia coasts (Fig. 1b), ranging from shallow water down to 100 m water depth (wd) (Fig. 1b). The R/V Minerva 1 was used to explore the deepest bathymetric interval, whereas a smaller boat (Calafuria ISSEL - property of CoNISMa) was used to investigate the shallowest one, for a total of 4400 km tracks.

Positional data were provided by a Hemisphere Crescent R-Series dGPS. Datum was WGS84 and the projection chosen for navigation and display was UTM fuse 33.

The remote technical devices we used included two models of dual frequency Side Scan Sonar (SSS) (the 100/500 kHz Klein3000 system and the 100/400 kHz EdgeTech 4-2000) and two different Multi-Beam Echosounders (MBES) (the 50kHz Teledyne Reson Seabat 8160 for the deepest interval, and the 455 kHz Teledyne Reson Seabat 8125 for the shallowest one). Water sound velocity was obtained by sound velocity profiles using a Teledyne Reson SVP15, whereas sound velocity sensors (Seabird SBE 21 device for the R/V Minerva 1 and Valeport miniSVP for the small boat) were used to compute the sound velocity at the head of the transducer. SSS operated at 200 m range setting and we reached 50% of overlap between adjacent lines. SSS data processing, performed using Triton ISIS (Triton Elics Information-TEI) suite software packages, produced geo-referenced gray-tone acoustic images of the seafloor at 0.5 m resolution. Only for SSS data acquired during the surveys on the R/V Minerva 1, the track of the fish was computed using the position of the ship, the length of the tow cable, and the elevation of the fish above the sea floor. On the small boat the SSS fish was fixed on a vertical pole, consequently a simple offset (from the dGPS antenna position) was used to obtain georeferenced SSS images. Acquired MBES data did not obtain a 100% of coverage of the surveyed areas, but provided very high-resolution Digital Terrain Models (DTMs) (i.e. from 30 cm up to 2 m grid cell size). The DTMs, provided by the MBES survey, was used for the final georectification of the processed SSS mosaic obtained from the R/V Minerva 1 surveys. A set of seismic lines have been acquired on board of the small boat in an area off the Bari port (Fig. 1b, c), using a parametric Sub-Bottom (SB) SBP Innomar 2000 (SES 2000): among them, we selected SB_130311, acquired with a frequency of 10 kHz, and line SB_113310 acquired with a frequency of 5 kHz, because they were crossing the diverse sub-bottom morphologies of C. Seismic-stratigraphic data have been processed using ISE Post-Processing Software, and the profiles were analyzed in order to stratigraphically constrain C build-ups and to investigate their inner structure and substrate following Damuth and Hayes (1977)

Video inspections have been made during all the oceanographic cruises to ground-truth remote dataset, using a ROV system (Prometeo) and a subaqueous trawled camera (Quasi-Stellar © Elettronica Enne – this latter was used only during the Issel surveys).

All data were integrated and analyzed using Geographic Information System (GIS) - based procedures (ArcGIS™ software) in order to identify, map and describe C habitat, according to the definition of Kostylev et al. (2001), who identified a marine benthic habitat as a spatially defined area where the physical, chemical, and biological environment is distinctly different from the surrounding environment. In term of scale, habitats have been mapped following meso- and macro-scale habitat definition of Greene et al. (1999).
C was identified according to the SSS texture description proposed in Bracchi et al. (2015). Here we extended the interpretation to the whole available dataset, from the Adriatic to the Ionian Sea (Fig. 1b).
Finally three case-study areas (Fig. 1b), where diverse morphotypes of coralligenous occur, have been selected to calculate Shape Index (SI) (McGarigal and Marks, 1995) values using System for Automated Geoscientific Analysis (SAGA), a free open source GIS software (Conrad et al., 2015). Through the module "Polygon Shape Indices", various indices have been computed in order to describe the shape of polygons representing C bioconstructions extracted from SSS imagery, based on: area, perimeter and maximum distance between the vertices of a polygon (Lang et al. 2007, Forman et al. 1986). SI were calculated using McGarigal and Marks (1995) equation that overcome size polygons dependence by comparing the perimeter/area ratios to a standard shape such as a square or circle (Aslan et al., 2007). Shape index value is = 1 when the patch is maximally compact and increases indefinitely as patch shape becomes more irregular. When SI value is around 1, it identifies discrete small C build-ups on the seafloor, whereas highest value are associated to large C platform with complex surface geometry.
The occurrence of the calcareous algal association of the C has been checked by spot analysis of its components, collected by SCUBA. Species identification is based on Bressan and Babbini (2003)

3. Results

Over the whole set of collected acoustic data, C morpho-acoustic facies have been identified by:
a) medium to strong SSS backscatter, according to Bracchi et al. (2015),
b) a topographic relief from 0.2 up to 4 m and steep flank,
c) a rigid inhomogeneous framework imaged by the indistinct prolonged nature of the seismic signal, well constrained in the stratigraphic sequence,
d) a variable plan-view geometry, that ranges from isolated sub metrical structures, to large (hundreds of m^2) planar outcrops, which dominate the seascape (Relini, 2009).
Spot analysis of the algal association provided evidence of the occurrence of a typical coralligenous live cover composed by peyssonneliaceans and crustose coralline algae, such as *Lithophyllum stictaeforme* (Areschoug) Hauck, *Lithothamnion*sp., *Mesophyllum alternans* (Foslie) Cabioch & Mendoza, *Titanoderma pustulatum* (Lamouroux) Näegeli.

3.1 C habitat, areal cover and depth range

According to the results of backscattering characterization proposed in Bracchi et al. (2015), and based on the ground-truth, we mapped a surface of 1026.05 km^2 of the Apulian continental shelf reporting the occurrence of coralligenous outcrops, and we calculated a total coverage of 388.32 km^2 of C, that is to say 38% of the mapped seafloor.

We distinguish C as sole habitat at the seafloor or in mosaic with other habitats, as follow:

1) C *sensu stricto* as the sole habitat with a total coverage of 167.24 km^2 (Fig. 2). It show metrical large tabular build-ups, representing the only habitat at the seafloor at the meso- and macroscale;
2) Mosaic of C and coarse detritic bottom with a total coverage of 94.20 km^2 (Fig. 2). C is characterized by small and discrete build-ups, isolated one to each other and singularly mapped, sometimes clustered in dozens;
3) Mosaic of C and muddy bottom with a total coverage of 7.42 km^2 (Fig. 2). C is characterized by small and discrete build-ups, isolated one to each other and singularly mapped, sometimes clustered in dozens;
4) Mosaic of C and *Posidonia* meadows with a total coverage of 103.90 km^2 (Fig. 2). C is characterized by small discrete build-ups usually isolated or formed by small groups.

C depth distribution as sole habitat or in mosaic with other habitats (Fig. 3) has a distinctive pattern. C *sensu stricto* shows two positive peaks between 20 and 40 m wd (60%) and from 80 to 90 m wd (50-60%) (Fig. 3). Mosaic of C and *Posidonia* meadows is identified in shallow water, between 10 and 40 m wd (maximum 35% at 20 m wd), whereas it disappears in deeper water (Fig. 3). Mosaic of C and muddy bottom is reported between 30 and 60 m wd, but with a coverage of less than 10%. Mosaic of C and coarse detritic bottom is distributed from 20 down to 100 m wd (Fig. 3), and in the deepest bathymetric interval it becomes the sole type of C expression.

3.2 C morphology

DTMs in the area well depict the different submarine landforms created by C as elevated, highly inhomogeneous and rough build-ups showing steep, often sub-vertical flanks (Fig. 4a). The lateral continuity of C outcrops is a very variable parameter and allowed distinguishing two morphological end-members in our dataset, as follow:

- Tabular build-up (Fig. 4a, b), representing the only framework with a continuous seafloor covering, up to dozens of m^2. At a larger scale the build-up shows a flat surface, whereas at a smaller scale it is strongly irregular (Fig. 4b) showing peaks alternating to holes, giving a typical crannied aspect. The elevation always ranges from 0.5 to 2 m (Fig. 4b), up to 4 m. The plan-view geometry of these outcrops is really variable: from circular to ellipsoidal to sub rectangular, more or less elongated, shapes, covering areas from few square meters to tens of square kilometers. In case of elongated structures, C interfingers with intra-areas characterized by other, typically mobile substrate (no build-ups), yielding a sort of “ridge and channel” pattern. This morphology type prevails in C *sensu strictu*.
- Individual sub-metrical to metrical build-up (Fig. 4a, c), with a coverage ranging from 1 to 10 m^2, and an elevation ranging from 0.2 to 2 m (Fig. 4c). In these cases, C forms tapered build-ups, often higher than wide (Fig. 4c, dotted box), but rarely also squat structures, practically coalescent (Fig. 4c, dotted circle) wider than high. Such structures are singularly recognizable, even if they appear clustered in dozens/hundreds at the seafloor (Fig. 4a, right). Also in this case the build-up surface has a rugose aspect on video records. This morphology type is reported for mosaic of C with other habitats.

Despite the identification of these two distinct morphotypes, several intermediate situations can be summarized as follows:

- Intermediate evolutionary phase between discrete individual build-ups, dispersed on the seafloor, and tabular build-ups (Fig. 5a, b). C outcrop appears, in this case, as the results of coalescence of discrete C build-ups that could slowly merge into more complex and large structures by progressive biogenic concretioning (Fig. 5a, b). At this stage the distinct shape is still identifiable singularly. Moreover, the areal coverage of the seafloor is not complete and C does not represent the only habitat in the seascape at the scale of meso- and macrohabitat. This morphology type is reported for C *sensu strictu*, for mosaic of C and coarse detritic bottom and rarely for C and *Posidonia* meadows.
- C outcrop showing a very distinctive shape. Figure 5c reports the case of C outcrop as elongated ribbons at the top of the flanks of an active submarine channel (note the occurrence of transversal bed-forms on the soft substrate, Fig. 5c). This morphology type is reported for C *sensu strictu* and mosaic of C and coarse detritic bottom.

A total of 3423 polygons detecting coralligenous have been mapped in the three case-study areas (Figs. 1b, white boxes, 6a, b). SI obtained values range from 1.02 to 12.80. Among all, 3302 (96.5%) polygons have a value ≤ 1,5 and correspond to patchy distribution on the seafloor (Fig. 6c, e) in which C forms usually very small (less than few meters large) discrete or isolated relief. A total of 96 polygons (2.8%) have a SI value ranging from 1,5 to 2, and generally form discrete constrained relief, and group of individual build-ups, not representing the solely habitat at the meso-scale; only 25 C polygons have SI > 2 (0.9%) and among them only 4 (0.2%) polygons have a value higher than 4. Polygons with SI > 2 correspond to large tabular build-ups, covering continuously the seafloor and characterizing the submarine landscape (Fig. 6d, e). Polygons with SI ranging from 1.5 to 2 correspond to build-ups with a complex shape representing an intermediate phase between small discrete reliefs and tabular structures. Total coverage of C polygons correspond to 8.07 km^2. It is interesting to note that polygons with SI > 2 , only 0.9% of total, cover 7.5 km^2 (93% of the mapped seafloor), whereas smaller reliefs, with SI < 2, cover only 0.57 km^2 (only 7% of the mapped seafloor).

3.3 Seismic-stratigraphic characterization of C frameworks

Over the investigated areas, SB enables distinguishing more than one reflectors in the seismic-stratigraphic sequence and consequently to stratigraphically constrain the different C morphotypes identified in our study (Fig. 7a, b, d, e).

In particular, we observed two different echotypes:

- for tabular structures, an indistinct echo with 1 or 2 discontinuous reflectors (Fig. 7a, b, c). The width of the indistinct echotype above the discontinuous reflectors corresponds to 2.5 up to 4 m (Fig. 7c);
- for individual structures, an indistinct echo with a single discontinuous reflector (Fig. 7d, e, f, g). The width of the indistinct echotype above the discontinuous reflector corresponds to 0.5 up to 1.5 m (Fig. 7f, g).

The seismic line SB_113310 (Fig. 7e) crosses both isolated (Fig. 7f) and large tabular (Fig. 7g) build-ups. In both cases, C creates a rugged morphology, producing an indistinct echo settled on a distinct reflector, which is sometimes laterally

discontinuous. Consequently, the identified echotype is associated to the biogenic framework, having a width ranging from 0.5 to 4 m, whereas the distinct reflector, occurring below both tabular and isolated build-ups, stratigraphically constrain the build-ups themselves.

4. Discussion

Acoustic mapping techniques are able to produce images of the seafloor with a suitable scale that properly depicts the extension of benthic habitats (Kenny et al., 2003; Savini, 2011, Brown et al., 2012). Such remote images are therefore the best tool to fill the gap in the current scientific knowledge about the occurrence of different C morphotypes, and to refine the too general, although still useful, definition of bank (Ballesteros, 2006). Furthermore, the acoustic devices allow measuring the specific morphometric features of C build-ups, precisely describing their pattern of distribution and quantifying their areal and bathymetric coverage.

4.1 C of Apulian continental shelf

C represents undoubtedly a key element for Apulian marine spatial management, covering 38% (Figs. 2, 3) of the seafloor between 10 and 100 m wd in the investigated area (Campiani et al., 2014). The occurrence of C habitat or mosaic of C with other habitats (Fig. 2) confirms the ability of this biocoenosis to adapt to different marine conditions, extending its distribution from anomalously shallow, possibly infralittoral, setting, down to the circalittoral zone (Pérès and Picard, 1964).
Within the study area C shows the maximum spatial dominance both in the 10-40 m wd and in the 70-90 m wd intervals (Fig. 3). In both cases it dominates and characterizes the marine seascape (C *sensu stricto*), forming large tabular banks. The bathymetric distribution should be firstly light dependent, since coralline algae are indicated as major bioconstructors in dim-light condition, typical of the circalittoral zone (Ballesteros, 2006). The 70-90 m wd interval is typically included in the circalittoral zone, and therefore it should be considered the most characteristic for the C development. In this belt we hypothesize the occurrence of appropriate substrate, such as inherited morphologies, as already indicated by Toscano and Sorgente (2002). Such relict substrates are presently buried, but could have favored and supported the development of C habitat in this deep environment. In the shallowest bathymetric interval (10-40 m wd), C occurs both as C *sensu stricto*, that occupies more than 40% of the seafloor, and in mosaic with *Posidonia* meadows. First of all, we quantitatively assessed the occurrence of C build-ups also in shallow waters, where fleshy algae and photophilous assemblages should be dominant. The reason of such possibly infralittoral C occurrence can be found in the local coincidence of different favorable environmental conditions still unexplained. The substrate of the C may be both mobile, as identified by subbottom profiler (Fig. 7), and hard. In the case of the Apulian continental shelf, the occurrence of a relict hard substrate (Toscano and Sorgente, 2002), should have fostered the present-day growth of well-structured C build-ups forming tabular banks.
Posidonia is a light-loving phanerogam that, in this case, competes for space with C in areas where these two different habitats co-occur. C build-ups settle among *Posidonia* plants and form very small, often individual, or coalescent structures, probably growing on mobile coarse sediments or on dead *Posidonia* "mattes" (the organo-sedimentary structure of roots and trapped sediment, leaving a relief on the seafloor after the death of the meadow).

Our results confirm the observations of Sarà (1968) and Sarà and Pulitzer-Finali (1970), describing a quite continuous C bank, with different substrate percentage cover from 10 to 100 m wd. The occurrence of mobile coarse sediment, testified by video inspections and analysis of seismic profiles (Fig. 7), is related to transport from land and *in situ* production and accumulation of biogenic carbonates (Toscano and Sorgente, 2002). In this case, C build-ups apparently develop on this type of substrate, and we can define it as C *de plateau* (Pérès and Picard, 1951, 1964) in its genetic definition.
The mosaic of C and muddy bottom occurs between 30 and 60 m wd only along the Adriatic continental shelf, north of the city of Brindisi (Fig. 5), where abundant mud is reported in surficial sediment (Parenzan, 1979; Spagnoli et al., 2010).

4.2 The geomorphological definition of C

The Apulian continental shelf hosts C with topographic relief (0.2 up to 4 m), lateral continuity ranging from less than 1 m up to hundreds of meters, and with a coverage up of several square kilometers, definitely falling into the bank category (Ballesteros, 2006). The term bank is evocative of build-ups showing lateral continuity, as specified in the definition: "*flat frameworks with thickness ranging from 0.5 to 4 m mainly built over more or less horizontal substrata"* (Ballesteros, 2006).
Apulian C build-ups are all characterized by the same order of thickness, and more or less the same horizontal substrate. Thus the limit lies in the spatial definition of the adjective "flat". The tabular build-ups (Figs. 4a, b, 7a-c) undoubtedly represent flat structures that can be ascribed to banks, but the individual build-ups (Figs. 4a, c, 7d-g) or the intermediate situations (Fig. 5) between the two end-members, can be hardly defined as banks.
SI has been widely used in terrestrial landscape ecology where it was introduced to indicate the divergence of the shape of a landscape patch from an ideal circle, taken as reference (Patton, 1975; Lóczy, 2002; Szabó – Csorba, 2009; Szabó, 2012).
SI is a powerful tool to describe a submarine landscape characterized by distinct C morphotypes often patchily distributed on the seafloor, although the potential application of such index in the marine environment appears underexploited (Boström et al., 2011; Pittman S.J. et al., 2011). Because of the variable and patchily distribution of C habitat on the seafloor, we calculated SI from our data in order to identify those SI values related to the observed distinct coralligenous formations. As we observed, studied C outcrops depict variable morphotypes, from large tabular platform with very irregular planar geometry view associated to highest value of SI (> 4), to small discrete squat build-ups, sometimes clustered in dozens but singularly mapped, associated to SI value < 1.5 (Fig. 6). Intermediate SI value (1.5-4) are associated to C build-ups corresponding to discrete but coalescent small build-ups, or small tabular platform not representing the only habitat at the seafloor at the meso- and macro-scale.
In order to accommodate the different observed morphotypes of infra-circalittoral C on sub-horizontal substrate (Fig. 7), we propose this new categorization (Table 1):

- ***TABULAR BANK:*** large tabular structure, with variable shape and geometry, a topographic relief ranging from 0.2 to 4 m, and width/height ratio > 1 (Figs. 4b, 5a, b). Consequently bank has a lateral continuity ranging from 4 m up to hundreds of m, covering completely the seafloor and representing the sole habitat in the marine seascape. SI values are largely > 2 (Fig. 6b, d, e). Banks (Sarà, 1968), algal reef (Bosence, 1983), mound shaped algal banks (Toscano

and Sorgente, 2002) and ridges (Bracchi et al., 2015) are included into this category.

- ***DISCRETE RELIEF:*** metrical structure, forming a topographic relief ranging from 0.2 to 1.5 m, in which the width/height ratio is ≤ 1 (Figs. 4c, 5a, c). SI values are ≤ 1,5. Consequently each structure has a distinct volume, although up to hundreds of them may occur clustered (Fig. 6b, c, e). Although clustered, they do not cover completely the sea floor and sediment patches occur among single build-ups. In rare cases the build-ups are clearly higher than broad, therefore they represent pillars, but in most cases C forms small square stocky relief. Heads and block patches (Sarà, 1968), vertical pillar (Di Geronimo et al., 2002), minute reef (Georgiadis et al., 2009) and columns (Bracchi et al., 2015) are ascribable to this category.
- ***HYBRID BANK:*** this category groups all the intermediate cases in which C shows variable lateral size, a topographic relief ranging from 0.2 to 2 m, and variable width/height usually > 1. SI values are > 1.5 but ≤ 2. It could be large as a tabular bank, but generally does not represent the solely habitat even at the mesoscale and the geometry or the outcrop shape is attributable to the case of coalescent but still isolated structures (Figs. 5a, b, c, 6b). Although the single structure is still detectable, the continuous coalescence could lead to the formation of a tabular bank. Such morphotype always occurs in combination with other habitats characterizing the seascape: it represents an intermediate phase between isolated build-ups and tabular bank. The spatial distribution of such structures could be explained as the consequence of local sedimentary and hydrodynamic conditions, as in the case of ribbons along an active channel (Fig. 5c).

4.3 (The problem of) The unknown substrate

Low frequencies parametric acoustic gives excellent resolution and good penetration into extremely shallow water. The substrate represents the key-element to distinguish the two existent bionomic C types (sub horizontal and mobile for "*de plateau*", or hard and variable oriented, often sub-vertical, for "*d'horizon inférieur de la roche littorale*", Pérès and Picard, 1964); nevertheless, according to our results, its recognition does not affect the C morphological categorization.

The infra-circalittoral Apulian C build-ups generally grew on more or less sub-horizontal substrate of variable nature. We can definitely exclude C *d'horizon inférieur de la roche littorale* category. Alternatively, we can define Apulian C as *de plateau*, according to its original definition (Pérès et Picard, 1964), limitedly to those instances when the unconsolidated nature of the substrate is verified. Based on video analysis, Apulian C build-ups are often surrounded by mobile sediment, although its occurrence on the seafloor does not necessarily mean that it serves as substrate for the C framework. We cannot exclude the outcropping of hard substrate or the occurrence of relict hard structures (Toscano and Sorgente, 2002), or again the existence of dead "mattes" in the shallowest depth range of C occurrence, which could act as solid substrate for C development.

Using a multi-parametric SB profiler, C vertical limit corresponds to a distinct reflector (Fig. 7c, e), sometimes laterally discontinuous. Above this reflector, exclusively an indistinct echo is recorded, which corresponds to C build-ups both in the case of tabular bank and discrete pillars (Fig. 7c, f, g). A distinct reflector is generally associated with

the occurrence of mobile sediment (Damuth and Hayes, 1977). Once assessed, as the examples reported in Figure 7, we can ascribe C outcrops (Fig. 7) to *de plateau* category (Pérès and Picard, 1951, 1964). However, at the same time we can claim that the nature of the substrate (in both cases mobile sediment) does not control the diverse present-day C morphotypes.

5. Conclusions

Seafloor mapping techniques allow obtaining large scale high-resolution seafloor images for the description of the seascape, the distribution and extent of benthic habitats. These are the main goals of the most recent European marine directives (such as Marine Strategy Framework Directive, European Community, 2008; Marine Spatial Planning Directive, European Community, 2014). From this scale of observation, we are able to improve the definition of bank *sensu* Ballesteros (2006) proposing a new easy-to-use categorization of C on sub-horizontal substrate, as follows:

1. C morpho-acoustic facies is characterized by: medium to strong SSS backscatter, build-ups with a topographic relief from 0.2 up to 4 m, steep flank, a rigid inhomogeneous framework, and variable geometry, from individual sub-metrical small structures, to large, continuous tabular banks with a coverage of several square kilometers.
2. It represents the most common monumental bioconstruction (Bressan et al., 2001) from the coast down to 100 m wd; it forms at least 4 different habitats: i) C *sensu stricto* as single habitat, ii) mosaic of C and *Posidonia* meadows, or 3-4) mosaic of C and both (iii) coarse or (iv) muddy bottoms. Its areal and bathymetric distribution is driven first by the dim-light dependence of its main builders (coralline algae).
3. The extrapolation of geometric parameters such height and SI are objective tool to define C morphotypes on seafloor. A new geomorphological categorization is proposed based on C acoustic and geo-morphometric properties: 1) tabular banks, 2) discrete reliefs, or 3) hybrid banks.

The nature of the substrate supporting the C buildups sometimes confirms the occurrence of C *de plateau* in its bionomic definition (Pérès and Picard, 1964; Bracchi et al., 2016). However, the bionomic approach appears inadequate for the purpose of C habitat mapping. The exploration of the C substrate is a complex task, with very interesting scientific implications but poor practical feed-back for large-scale mapping. In the framework of the current increasing need for a sustainable coastal management of marine resources, the basic information, such as habitat mapping, should not require time-consuming explorations of the sub-surface or imply subjective interpretations. Within the investigated sub-horizontal settings, the occurrence of hard *vs* mobile substrate does not affect the superficial morphological expression of the C. Therefore, for the purpose and the scale of habitat mapping, we suggest to avoid all genetically-constrained definitions of C and replace them with a descriptive morphotype categorization proposed here, based on simple and clear observations, quantitative and objective analysis.

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Captions

Figure 1: Geographical setting of the surveys: a) map of the Mediterranean sea; the inset b indicates the Apulia region, Southern Italy; b) the Apulian continental shelf, with the indication of the 100 m isobath (black line). Black and grey lines indicate Multibeam (MBES), Sub-Bottom (SB) and Side Scan Sonar (SSS) tracks. Stars indicate the sites of video inspections. Black point localizes the direct sampling site. White polygons localize case-study areas for Shape Index (SI) extrapolation. Inset "c" indicates the area of sub-bottom survey. c) Magnification of SB inspection area with the indication of SB tracks.

Figure 2: C habitats distribution along Apulian continental shelf.

Figure 3: Graph of areal distribution, expressed in cumulate percentage, of C habitats *per* 10 m bathymetric intervals from 10 to 100 m wd.

Figure 4: C morphology description: a) Digital terrain model with 30 cm resolution, reporting examples of different adjacent structures of C outcrops, in particular tabular structures on the left and isolated or discrete structures on the right. Topographic profiles are reported in b) for tabular structures and c) for isolated structures respectively. Dotted box in c) indicates structures clearly higher than wide, whereas dotted circle indicates an example of a more squat structure, practically the coalescence of more than one structure, with rugose surface.

Figure 5: Intermediate morphological expressions of C: a) and b) report C at an intermediate evolutionary phase between isolated structures, dispersed over the seafloor, and tabular structures, as the result of coalescence of discrete build-ups; c) C ribbons. In all cases, dotted lines contoured C build-ups. All figures are 3D surface mapping obtained using Surfer ® v10.

Figure 6: Automatic mapping of C polygons based on SI values: a) geographical setting with the indication of the studied site; b) case study site: brown polygons are associated to coralligenous with SI > 2, pink polygons with SI ≤ 1.5, polygon with graduated color from pink to brown have SI ranging from 1.5 up to 2; c) a magnification of pink polygons (= small discrete reliefs); d) a magnification of brown polygons (= large platforms); e) histogram of the distribution of mapped polygons into SI classes. In the histogram, the column of SI class 1.5-2 with a color gradation from pink to brown, corresponds to the passage, in term of identified morphotypes, from small discrete and isolated structure to larger morphotype.

Figure 7: Selected SB profiles cross both tabular and isolated C structures. a) SSS mosaic of tabular build-ups, dot-contoured, with the indication of SB_130311 track; b) SB_130311 seismic line. Dotted box magnified in c; c) detail on the echotype associated with tabular C build-ups: an indistinct echotype with 2 distinct reflectors (arrow); d) SSS mosaic of both tabular and isolated build-ups, both dot-contoured, with

the indication of SB_113310 track; e) SB_113310 seismic line. Dotted and dashed boxes magnified in f and g respectively; f) detail of the echotype associated with isolated C build-ups: an indistinct echotype with 1 distinct reflectors (arrow); g) detail of the echotype associated with tabular C build-ups: an indistinct echotype with 1 distinct reflectors (arrow).

Table 1: Summary of the newly proposed categories of C morphotypes, with the indication of the main geometric parameters to identify and describe them; n/a is for not applicable.

		Bank			Rim
		Tabular bank	Discrete relief	Hybrid bank	
Substrate geometry	Sub-horizontal	X	X	X	
	Sub-vertical				X
Habitat mosaic	Coralligenous *sensu strictu*	X		X	
	Mosaic of Coralligenous and coarse detritic bottom		X	X	
	Mosaic of Coralligenous and muddy bottom		X		
	Mosaic of Coralligenous and *Posidonia* meadows		X		
Height		0.2 to 4 m	0.2 to 1.5 m	0.2 to 2 m	n/a
Width/height ratio		Always > 1	Always ≤1	Variable	n/a
SI		Always > 2	Always ≤1.5	1.5 > SI ≤ 2	n/a

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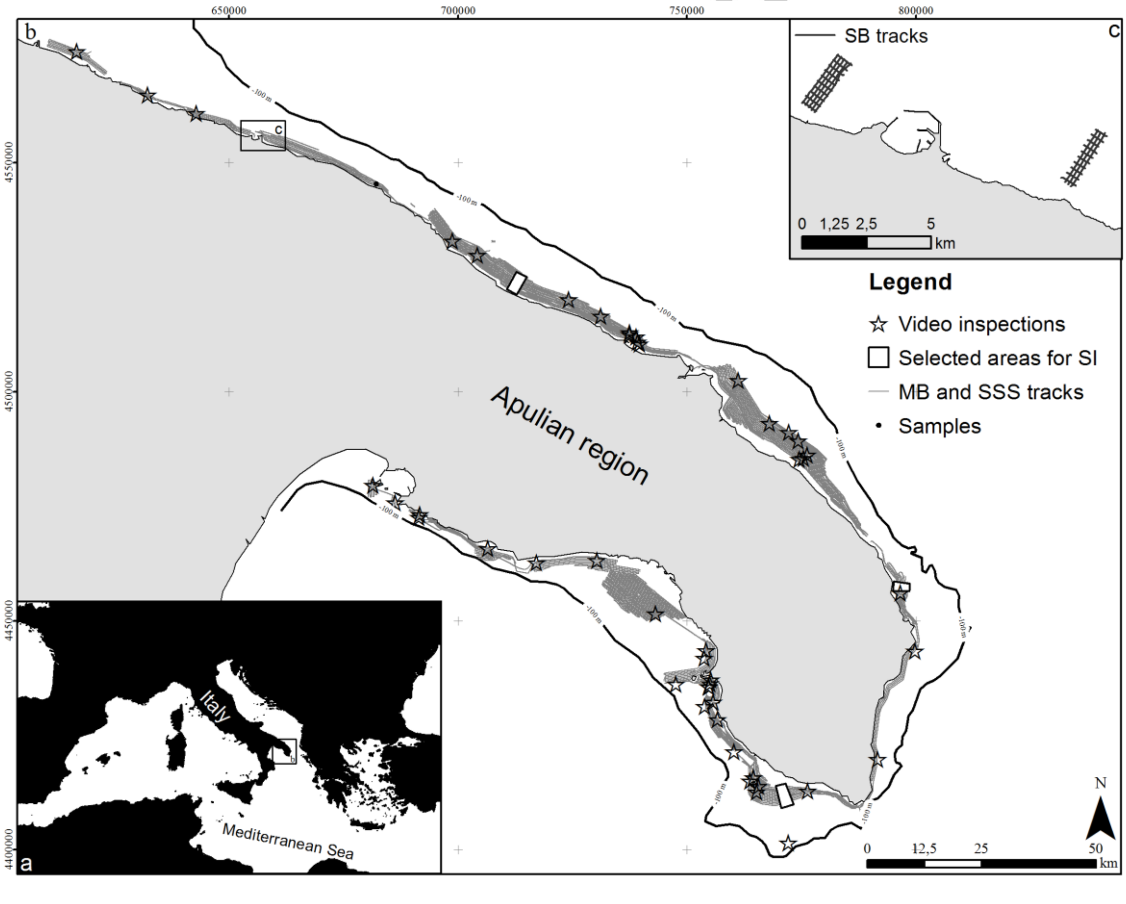

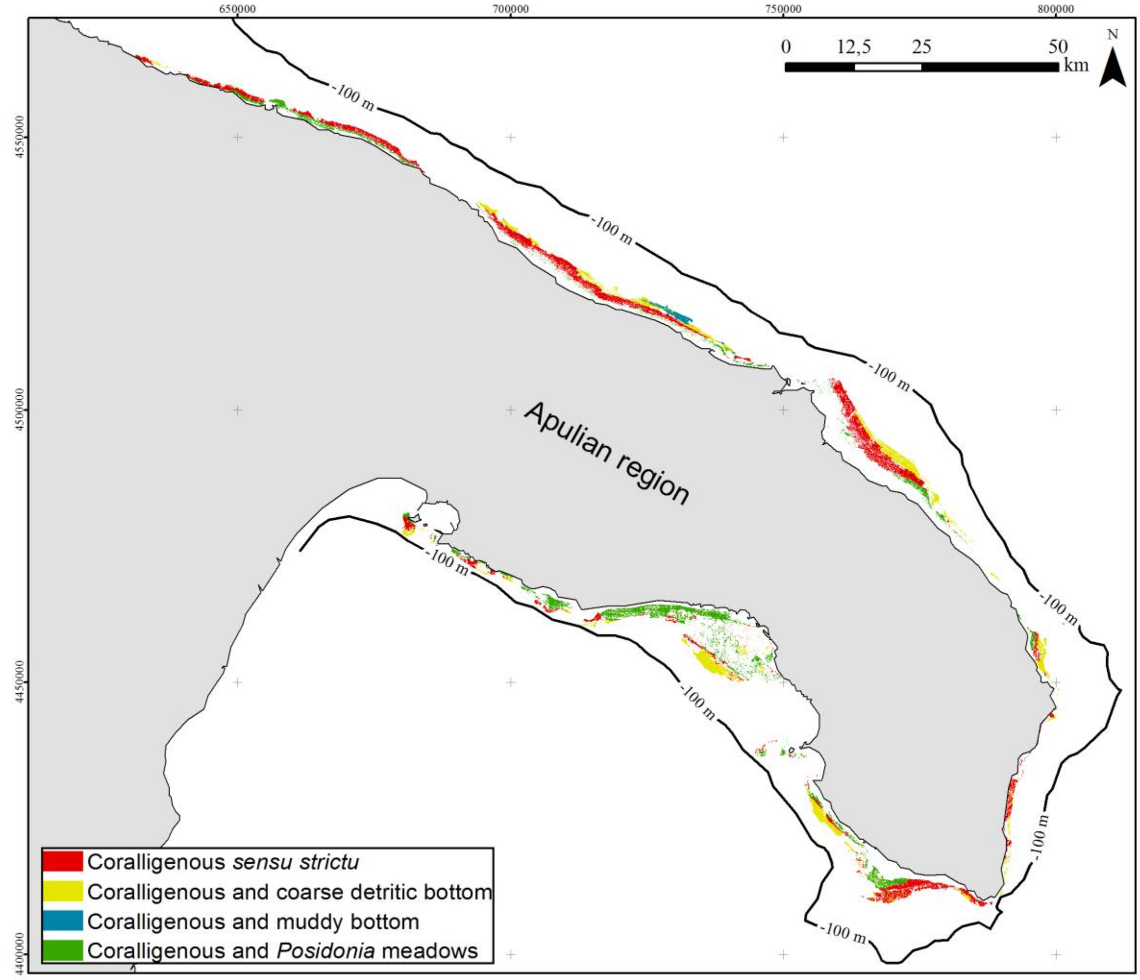
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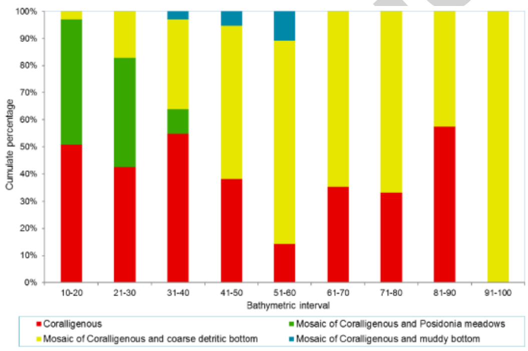
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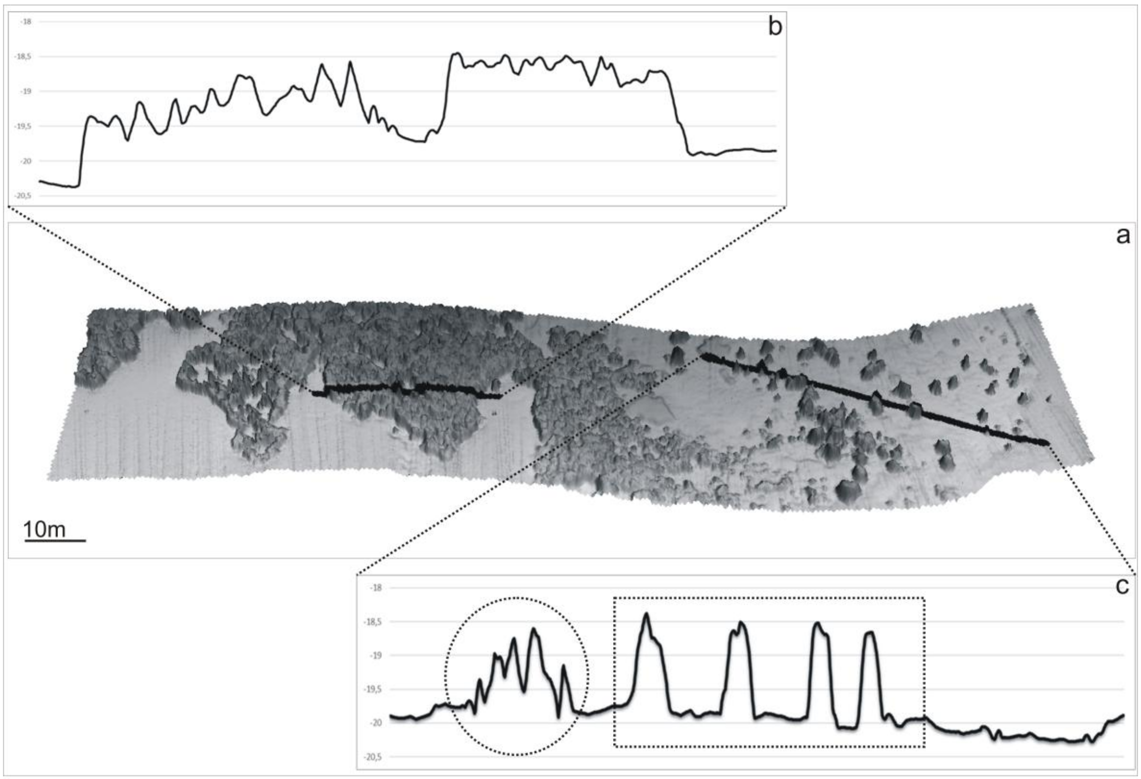
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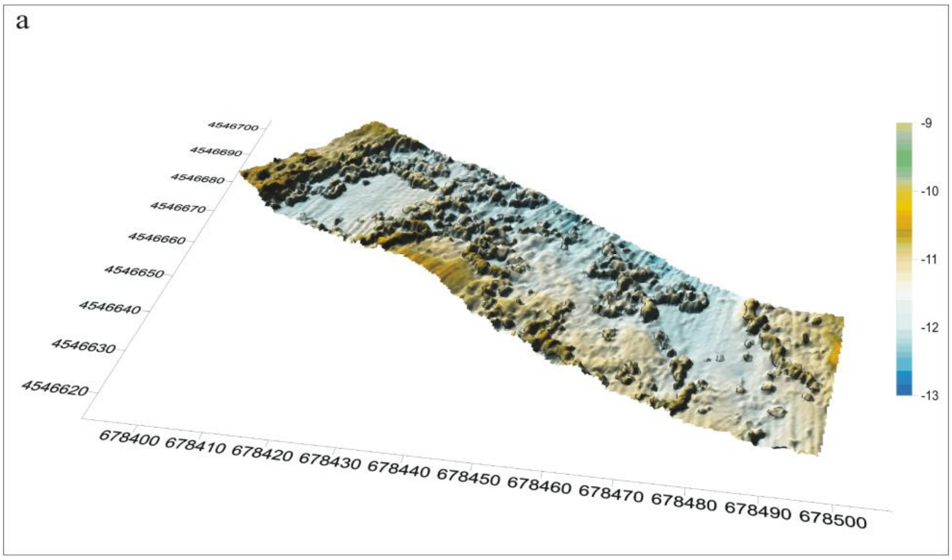
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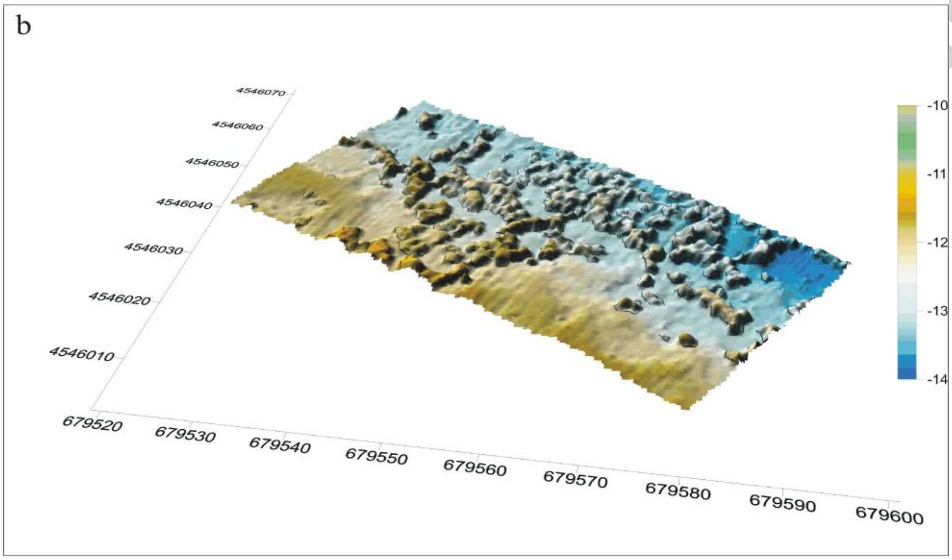
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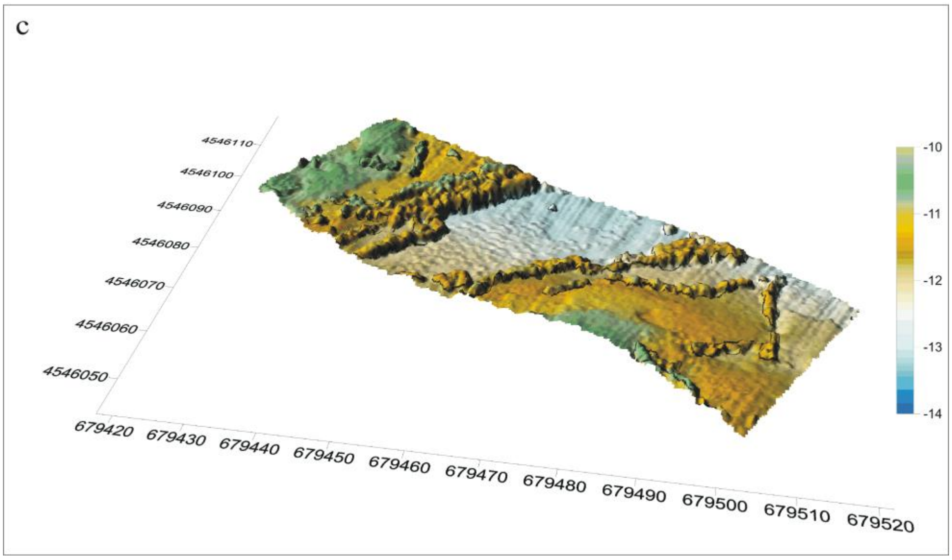
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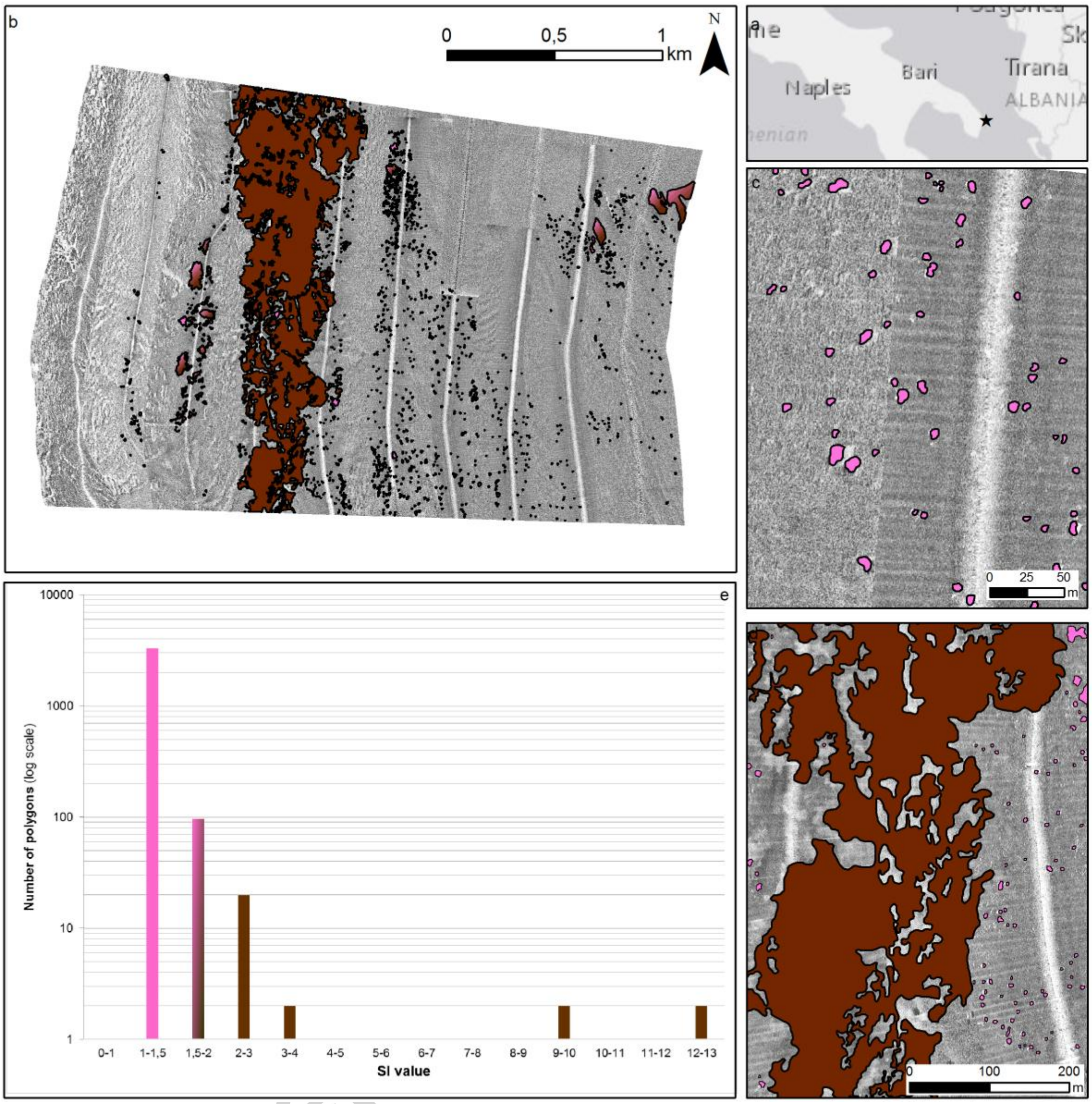

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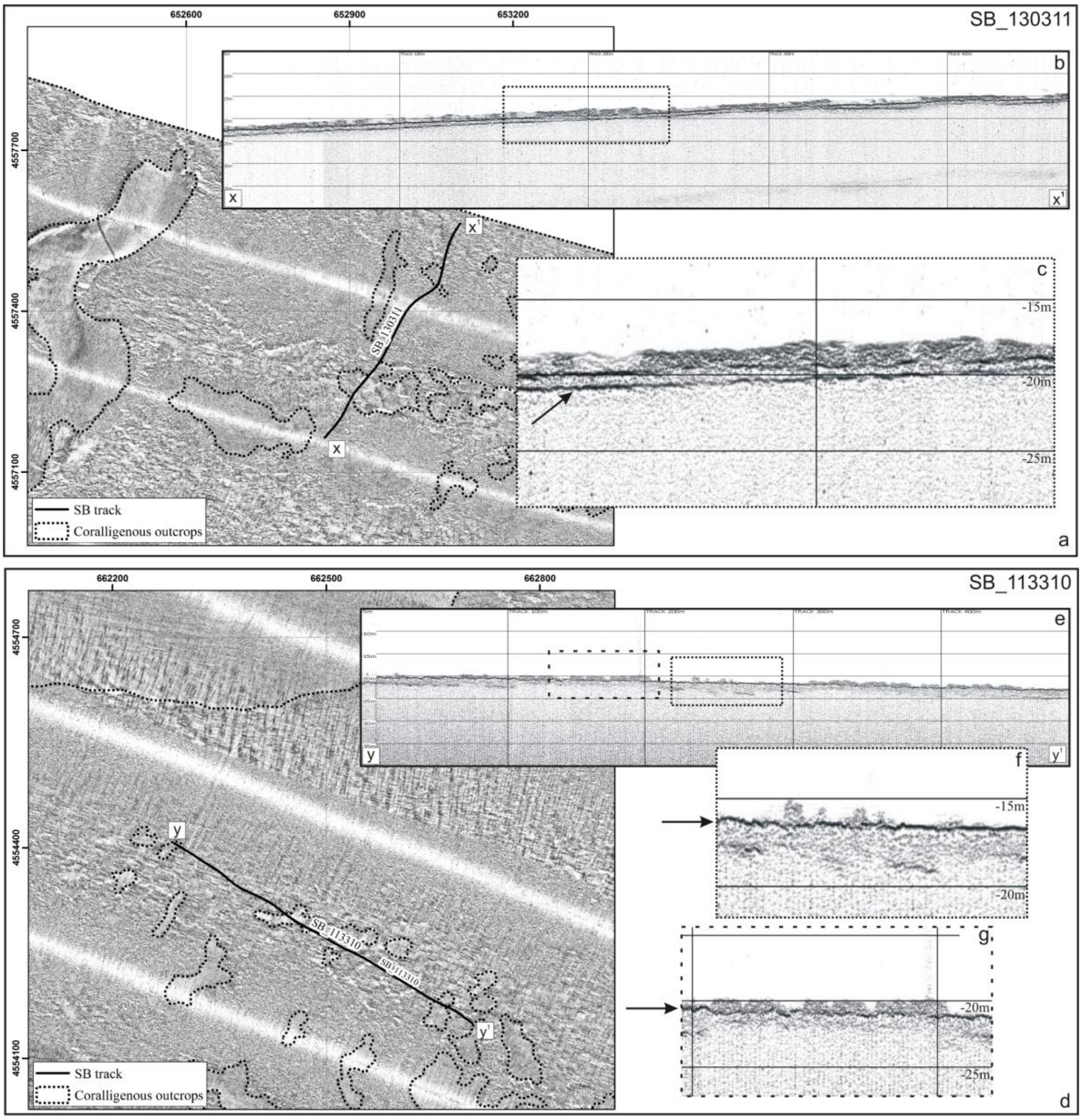

Highlights

C morphotypes have been investigated along Apulian continental shelf, Italy

C occurs as C *sensu stricto* as a single habitat at meso-macro scale, or in mosaic with *Posidonia* meadows, and either coarse or muddy bottoms.

C form three morphotypes on sub-horizontal substrate: 1) tabular banks, 2) discrete reliefs, or 3) hybrid banks, easily distinguishable based on acoustic and geo-morphometric properties (height and Shape Index).

The bionomic approach appears inadequate for C habitat mapping: we suggest to avoid all C genetically-constrained definitions and replace them with the morphotype categorization.